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## DEVELOPMENT OF REAL TIME ULTRASONIC IMAGING

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### Abstract

The paper investigates the real time imaging of corrosion and cracks on both the front and back surfaces of thin plate. A real time imaging system utilizing an innovative CCD camera to render the sound waves visible is used in conjunction with ultrasonic transducers as illuminators to generate video pictures of discontinuities. Longitudinal and shear waves are investigated as means to detect corrosion of various severities. Samples were fabricated in a salt fog environment to simulate corrosion under painted surfaces. Fatigue cracks were grown using reversed bending apparatus. Experimental results and video results of inspection are presented.

### Key Words:

Ultrasonic, NDI, Imaging, Corrosion, Inspection

### Introduction:

Imperium Inc. developed the concept of imaging sound waves in a water media using a modified infrared charge coupled device (CCD) during the 1997 time period. Since then continued development of the immersion "Acoustocam" system has taken place in partnership with Naval Aviation (NAVAIR) through small business innovative research (SBIR) contracts and with the Strategic Environmental Research and Development Program (SERDP). Hardware and enabling software have progressed to the point of providing clear real time TV images by several means using the camera.

### Experimental Methods:

The system utilizes a modified CCD camera fabricated by Imperium Inc (Figure 1). The CCD chip is coated with a piezoelectric material known as polyvinyl difluoride (PVDF) which enables the conversion of mechanical energy to charge the CCD chip. The system architecture is shown as Figure 2. An ultrasonic transducer is used to generate mechanical waves and is energized by a pulser. The timing for the pulse generation is provided by a delay card in the PC which gives a timed delay from the camera sync

signal. The video output from the camera is either by analog signal or digital signal. The digital signal is fed to an imaging card in the PC.

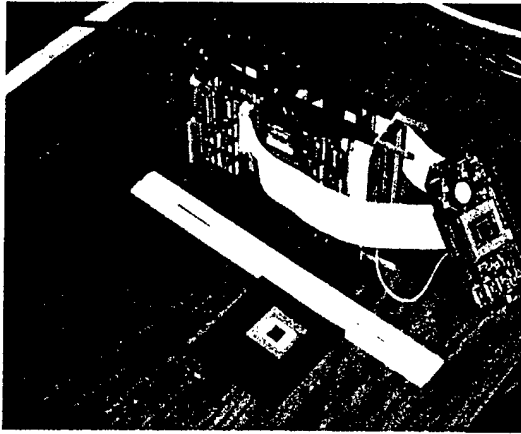


Figure 1. Camera Components

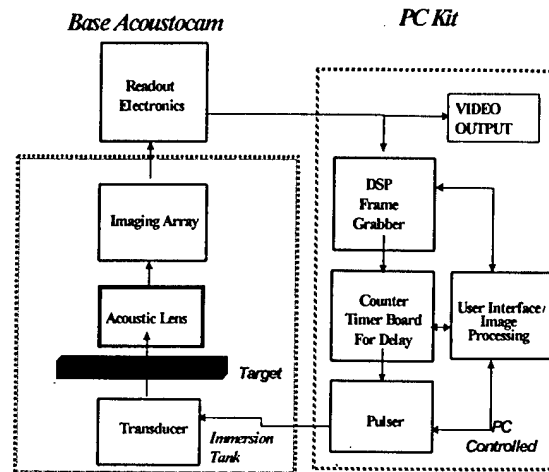


Figure 2. System Architecture

Initial work was performed by passing the sound energy directly through the test piece to the camera. This through transmission is the least complicated method which also had the benefit of requiring the least acoustic energy from the ultrasonic transducers and ultrasonic pulser utilized (Figure 3). Initial setup of the immersion tank involved the mounting of a low impedance diaphragm on one end of the tank for the camera to look through. The camera was manufactured with a block of aqualene cemented on the imaging chip. A suitable liquid or gel is applied to the diaphragm and the camera is

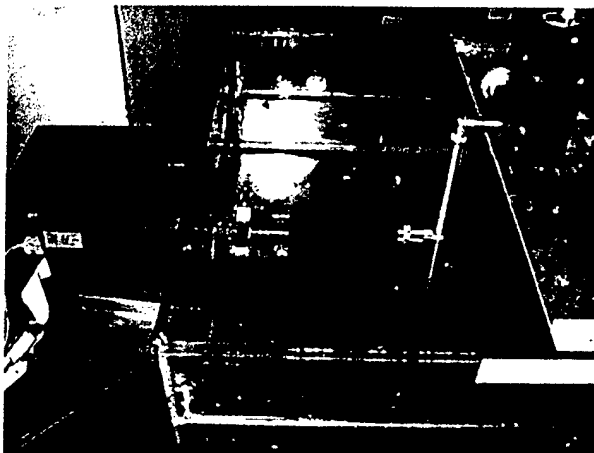


Figure 3. Through Transmission Imaging



Figure 4. Angle Beam Imaging with Lucite Wedge

moved into contact with the diaphragm, providing physical contact between the water and the CCD chip. A small PC manufactured in the "breadbox" configuration for ease of use was incorporated in the system to accommodate full size computer cards for control purposes and to display data. The ultrasonic transducer is energized by the pulser when

triggered by the delay card in the PC. The pulse passes through the test item and reaches the CCD chip just as it is energized by the camera sync circuit. The electronic window for viewing the wave is kept small to minimize interference.

A second configuration was attempted by introducing the ultrasonic beam into thin aluminum sheet at an angle using a Lucite wedge (Figure 4). The beam was allowed to bounce several times within the sheet and exit back through the first side to the camera without going through the back surface. A thin sheet was glued to the back of the target plate to provide an air gap behind the plate to eliminate signal loss through the back of the sheet. This allowed a 100% reflection of the beam from the back surface and simulated a hand held unit used outside the water tank to inspect the outer skin of something like an aircraft. This method was successful but was replaced by an immerseable transducer mounted on a stand which had 5 modes of adjustment, allowing many configurations to be attempted. This configuration is shown as Figure 5. The UT

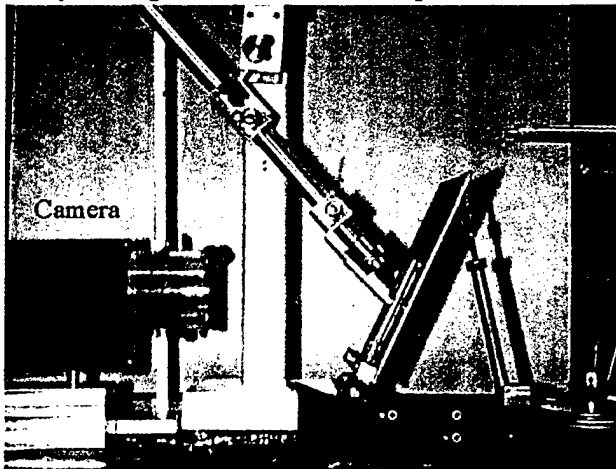


Figure 5. Adjustable Angle Beam Setup

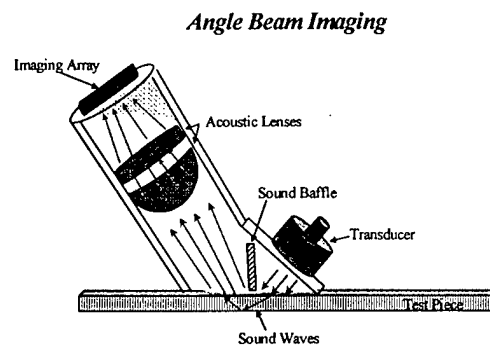


Figure 6. Architecture of the Portable Angle Beam Head

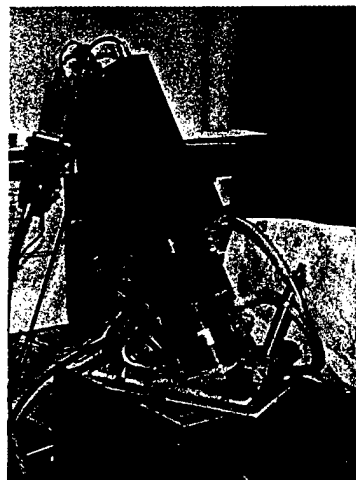
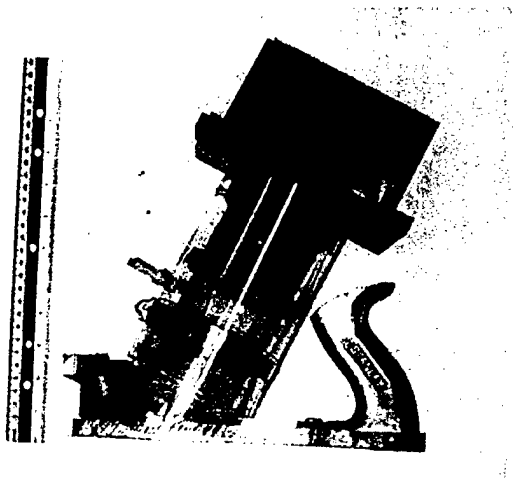


Figure 7. The Portable Angle Beam Inspection Head

beam was stronger using this configuration because of the elimination of an interface and the absorption by Lucite.

The configuration utilized in the immersion tank was redesigned as a portable unit when the success of the set up was established (Figure 6&7). The portable angle inspection head has been found to be as successful as it was when set up in the immersion tank.

## **Experimental Results**

### **Through Transmission Inspection Results**

Imaging of targets by passing the ultrasonic beam through them is analogous to radiographic inspection in that a shadowgraph is formed. The image is remarkably similar to real time radiography with a few exceptions. Gamma radiation is attenuated proportionally to the thickness and density of the material it passes through. Sound waves are also attenuated proportionally to the thickness of the material, but are also reflected and refracted at interfaces like light waves. The reflection becomes total when a large mismatch of acoustic impedance between the two materials is involved. Air and any solid are one example of an interface that totally reflects.

The energy required to form a clear picture using the present first generation CCD chip developed by Imperium is somewhat more than that required for normal ultrasonic NDI inspection. The first pulser utilized was the MP215 manufactured by Tektronix. The 120 volt pulse generated provided clear images but was limited in application because of the need for more power. This was replaced by the MP275 with a pulse of approximately 250 volt was sufficient for many more trials, but was replaced by a pulser capable of 1,000 volts supplied by Imperium Inc. Through transmission studies showed that exfoliation corrosion was very easily imaged (Figure 8) as was detail in a riveted



Figure 8. Exfoliation Corrosion (left), Riveted sheet (middle), and a Thin Fatigue Crack in 0.062 inch aluminum sheet (right)

aluminum sheet or vertical cracks in thin aluminum sheet.

Imaging of composite panels showed that the fibers themselves could be easily imaged in through transmission revealing fiber direction (Figure 9). Disbonds between composite layers were easily imaged because the crack interface does not allow the passage of sound resulting in dark areas in through transmission mode (Figure 10). Large areas of composite panels could be inspected in a short time because of the image clarity and the

real time nature of the images. The size of the field imaged by the fabricated lenses was chosen to optimize the size while keeping the resolution required for optimal inspection. New CCD chips are under manufacture and will enable different inspection field sizes.

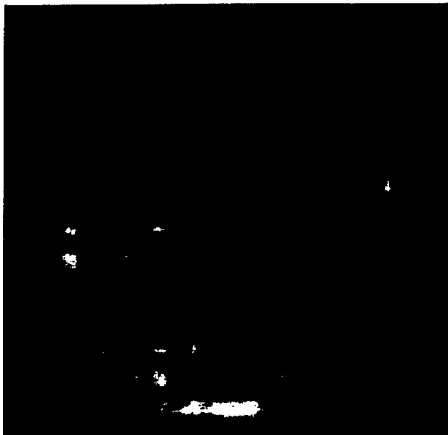


Figure 9. Image of Composite Fibers



Figure 10. Delaminated Composite Panel

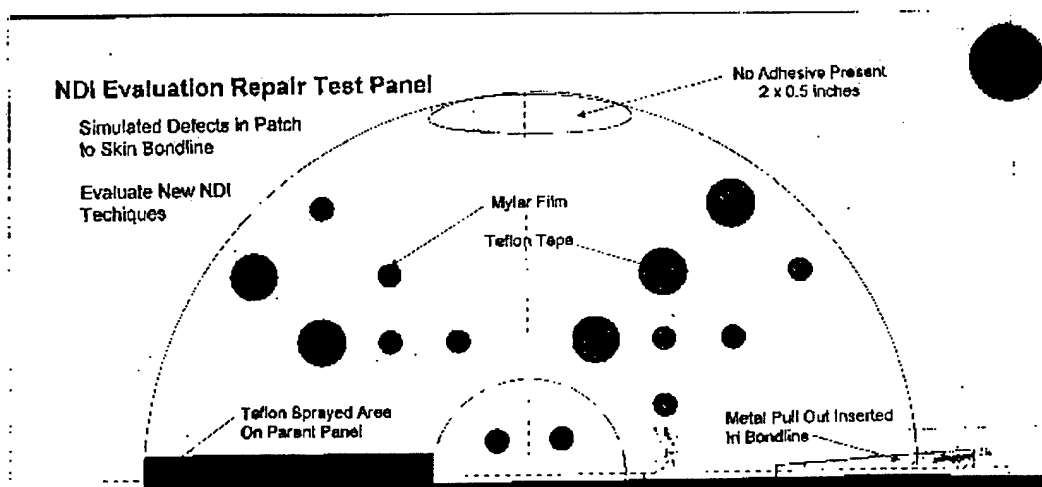


Figure 11. NDI Repair Test Panel layout



Figure 12. Sound image of the composite panel

Examination of an NDI Evaluation Repair Test Panel (Figure 11) showed remarkable definition of all aspects of the panel. The fibers themselves were clearly defined in the single layer areas at the outer fringes of the panel. The edges of the multiple circular patches applied to the panel were clearly defined as was the circular piece of Teflon tape (Figure 12) inserted between the patch layers. Penetration of the beam through the multiple layers presented no problem although the definition of the fibers within layers was lost when more than a few layers were imaged.

### Angle Beam Inspection Results

Angle beam inspection consists of introducing a sound beam into the part at an angle, allowing the beam to bounce from the bottom surface and then leave the part from the top surface (again at an angle) on the same side as it entered. Angle beam illumination of thin aluminum sheet was first successful on 9/2/99 in the imaging of flat bottom holes in 0.125 thick aluminum sheet. The trials were expanded to a successful simultaneous imaging of both near side and far side holes the same week. The method first utilized a plastic wedge commercially obtained with a 1"x ½ " 5 MHz transducer for best imaging. This method gave a fixed angle beam which could be introduced into the plate wherever the wedge was held against the plate.

The test jig shown in Figure 5 allowed the beam to be varied in placement and angle. A beam was found to give good results when aligned to refract at 60 to 70 degrees inside the plate, reflect between the back surface and front surface several times, refract at the front surface and then propagate into the camera. An angle between the test piece and the camera of approximately 28 degrees was found to maximize the brightness of the beam in this configuration. Initial trials used a 1/16 inch thick 7075 T6 plate with a 3/16 inch diameter flat bottom hole (FBH) 0.010 inch deep on both the front surface and the back surface of the plate. A thin sheet was glued to the back surface to exclude water. The near (top) surface is seen first followed by the back surface (Figure 13 left). The inspection is performed entirely from the front surface.



Figure 13. Angle Beam Images. A single back surface 0.010" deep 3/16" diameter flat bottom hole (left). Heavy back surface exfoliation corrosion (middle) and light back surface exfoliation corrosion (right). The multiple bounces of the beam cause multiple images of the discontinuities.

An extensive effort was made to make reproducible corrosion samples. One aluminum alloy (7075 T6) was chosen for the effort as being common in the aircraft industry and easily corroded. Trials using samples corroded in a salt fog environment showed that the degree of corrosion could be controlled by the duration of exposure and the corrosion could be produced in selected locations by protecting all the sample except those locations with a chromated primer and top coat of paint. Imaging of corroded samples representing as little as ½ % of weight loss were easily imaged using through transmission configuration. Angle beam inspection was not as clear but also showed the

corrosion (Figure 13, right). Corrosion pits representative of 5% weight loss were exceedingly plain when imaged either in through transmission or angle beam (Figure 13, middle). The angle beam images of flat bottom holes or larger corrosion pits (0.020 inch or so in diameter) appear as a string of discontinuities because of the bouncing of the beam between surfaces and the shadow formed by the defect. All images after the first one are the shadows. Smaller discontinuities have shadows which are obscured by beam scatter.

## **DISCUSSION OF RESULTS**

The goal of this project is the detection of corrosion and fatigue cracks on the second surface of thin aluminum sheet through paint. The first year has seen the development of through transmission inspection which gives very good penetration through a variety of materials including aluminum, carbon composites, thick glass fiber composites and some honeycomb structures with excellent images showing details as small as composite fibers and very small diameter pits in aluminum sheet.

A second inspection mode of either longitudinal or shear ultrasonic waves reflecting between the two surfaces of aluminum sheet has given very good results with good sensitivity through as much as three layers of paint when imaging pits 0.030 inch in diameter. The obvious advantage of this method over through transmission is that it requires access to only one surface. Airplane wings and fuselage components could therefore be inspected with no disassembly.

Imperium Inc. has had good results with a test head which directs the beam straight down into the target and images the reflected energy which bounces back up to the camera. This method has great promise for applications where the test object is thicker than the thin aluminum sheet used in aircraft, and may be useful for this with further improvement.

## **CONCLUSIONS**

Ultrasonic inspections are performed daily by thousands of engineers and technicians in the United States alone. These individuals have never been able to make more than a guess about the nature of the discontinuities found in the sheet, plate, weld, composite panel, etc. because of the lack of information gleaned from the oscilloscope screen used (amplitude and time delay). Imaging of the same sound beam allows instant identification of the source of the signal with the possibility of accurate evaluation of the size, shape, and origin of the discontinuity. The great advantage of this is that the necessity for grinding out every signal source is negated. Only those discontinuities of a size, type, shape and placement which might cause failure need to be repaired.

Further development can now be concentrated on minimizing the size of the portable test heads developed and adapting the test heads to new specimen geometries such as curved (wing) surfaces. Other future applications might include heavy gauge welds in plate, corrosion in piping, welds in piping,



## **ACKNOWLEDGEMENTS**

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